# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From – To)* |
|---|---|---|
| 19 October 2005 | Final Report | 06/11/2003-12/31/2003 |

**4. TITLE AND SUBTITLE**

2003 SOLAS Summer School

**5a. CONTRACT NUMBERS**

**5b. GRANT NUMBER**

N00014-03-1-0882

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

Dr. Wade R. McGillis

**5d. PROJECT NUMBER**

13088200

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Applied Ocean Physics and Engineering Dept.
Woods Hole Oceanographic Institution
98 Water Street, MS #12
Woods Hole, MA 02543

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING/MONITORING ACRONYM(S)**

ONR

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

In 2003, the United States provided support for the participation of 18 students, three research assistants, and seven lecturers in the first Surface Ocean Lower Atmosphere Study (SOLAS) Summer School. The purpose of this school was to introduce graduate students and young researchers to different components of SOLAS research including biogeochemical interactions and feedbacks, exchange processes, and air-sea fluxes. The SOLAS summer school used a theoretical framework, practical exercises, and laboratory experiments to promote an intensive learning environment. Most importantly, it provided the opportunity for young researchers interested in SOLAS science to meet one another and interact with lecturers currently researching these important global issues.

**15. SUBJECT TERMS**

air-sea interaction, global change, SOLAS school

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL | 10 | Wade R. McGillis |
| | | | | | **19 b. TELEPHONE NUMBER** *(Include are code)* |
| | | | | | (508) 289-3325 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std. Z39-18

# 2003 SOLAS Summer School Final Report

Wade R. McGillis
Woods Hole Oceanographic Institution, MS #12, 98 Water Street, Woods Hole, MA 02543
phone: (508) 289-3325 fax: (508) 457-2194 email: wmcgillis@whoi.edu

Award Number: N00014-03-1-0882

## Executive Summary

In 2003, the United States provided support for the participation of 18 students, three research assistants, and seven lecturers in the first Surface Ocean Lower Atmosphere Study (SOLAS) Summer School. The purpose of this school was to introduce graduate students and young researchers to different components of SOLAS research including biogeochemical interactions and feedbacks, exchange processes, and air-sea fluxes. Support was provided through grants from: NASA (contact: Charles Trees); NSF (contact: Anne-Marie Schmoltner); NOAA (contact: Kathy Tedesco); and ONR (contact: Ronald Ferek).

**A statistical and informational summary of the United States included:**

- 11 Women Students of the 18 Students
- 7 Male Students of the 18 Students
- 4 Postdoctoral Scientists of the 18 Students
- 14 Graduate Students of the 18 Students
- United States Faculty for the participating students included: Pamela Madson; Raphael Kudela; Jorge Sarmiento; Steve Emerson; Richard Barber; Ronald Prinn; Paul Quay; Michael Bender; Nicky Gruber; Eric Saltzman; Edward Boyle; Janet Campbell; David Siegel; Paul Crutzen; and Joan Willey.
- United States Institutions for the participating students included: Stanford University; University of California – Santa Cruz; Princeton University; University of Washington; Duke University; Massachusetts Institute of Technology; University of California – Los Angeles; University of California – Irvine; University of New Hampshire; University of California – Santa Barbara; University of California – San Diego, Scripps; and the University of North Carolina.
- Lectures from the United States included: Wade McGillis (Columbia University); Rik Wanninkhof (NOAA/AOML); Mary-Elana Carr (JPL); David Erickson; (DOE/ORNL); Raymond Najjar (Pennsylvania State University); and Eric Saltzman (University of California – Irvine).
- The US also provided a practical workshop on air-sea processes and atmospheric fluxes.

More than 70 students from 20 nations attended the school, held on the French island of Corsica from late June to mid July as a joint project of the International Geosphere-Biosphere Programme (IGBP), the Scientific Committee for Oceanic Research (SCOR), the World Climate Research Programme (WCRP) and the Commission for Atmospheric Chemistry and Global Pollution (CACGP).

## Background: United States SOLAS Program

The Surface Ocean Lower Atmosphere Study (SOLAS) is an international research initiative focusing on biogeochemical interactions and feedbacks, exchange processes, and air-sea fluxes. The international SOLAS program has recently released a science plan and implementation strategy (**www.solas-int.org**). Sub-groups are writing detailed implementation plans for the three different international foci. The US Advisory Group and the organization and framework of the Science Implementation Strategy plan is shown in Figure 1.

The international structure provides an over-arching and integrating theme to this interdisciplinary science program (**http://www.uea.ac.uk/env/solas/org/whatis.html**). The framework of the multi-disciplinary science goals are partitioned into three SOLAS Implementation Groups (IMPs). The Implementation Groups (IMPs) of SOLAS are charged with producing detailed plans of how to achieve the goals of SOLAS and aiding the implementation of these plans. The goals are outlined in the Science Plan and Implementation Strategy and the more detailed Implementation Plans produced by each group. The IMPs are comprised of interdisciplinary scientists with multi-nation representation. There are three SOLAS IMPs, corresponding to the three science foci, namely: IMP 1: Biogeochemical Interactions and Feedbacks Between Ocean and Atmosphere; IMP 2: Exchange Processes at the Air-Sea Interface and the Role of Transport and Transformation in the Atmospheric and Oceanic Boundary Layers; and IMP 3: Air-Sea Flux of $CO_2$ and Other Long-Lived Radiatively-Active Gases.

The goal of SOLAS is:

***To achieve a quantitative understanding of the key biogeochemical-physical interactions between the ocean and atmosphere, including how this coupled system affects and is affected by climate and environmental change***

The US SOLAS has adopted this plan as a framework for the USA complementary efforts. The program will work in concert with a unified international research team. The USA SOLAS Advisory group includes Richard Feely, Wade McGillis, David Erickson, Paty Matrai, Barry Huebert, Bill Miller, Peter Schlosser, Ken Melville, Bill Keene, Eric Saltzman, Chris Fairall, David Farmer, Bob Duce, David Siegel, and William Jenkins.

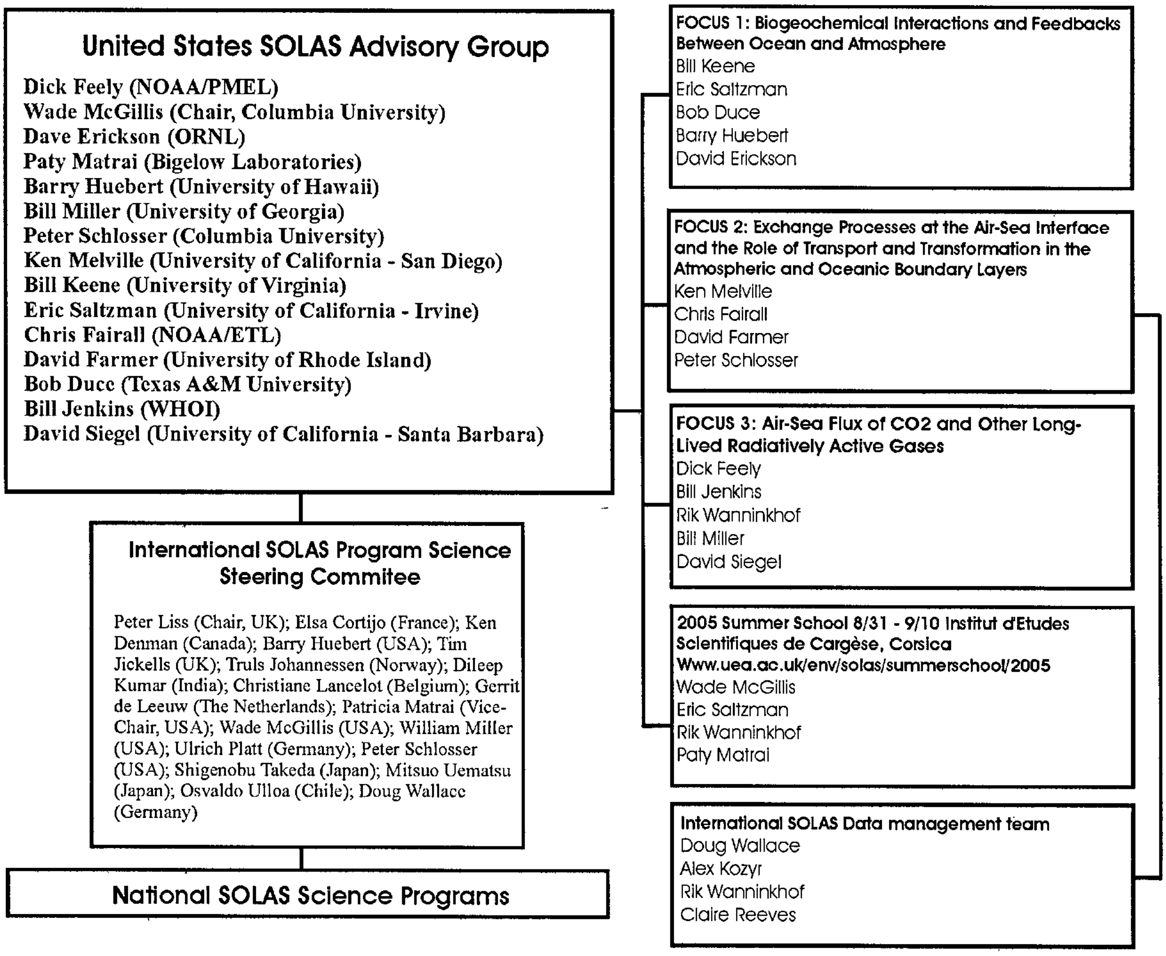


**Figure 1: Members, structure, and activities of the United States SOLAS Advisory Committee**

## 2003 SOLAS Summer School

The interdisciplinary nature of the SOLAS summer school offered a wide range of educational opportunities. Students met at the Institut d'Études Scientifiques de Cargèse overlooking the Mediterranean Sea. The course used a theoretical framework, practical exercises and laboratory experiments to create an intensive learning environment. It also provided an opportunity for young researchers interested in SOLAS science to meet one another and to interact with lecturers currently investigating a number of important global issues.

Lectures covered such topics as the global carbon cycle, biogeochemical modeling, gas exchange, physical and biogeochemical processes in the coastal zone, data assimilation, marine ecology, and atmospheric chemistry. Lectures can be viewed on the summer school web site (http://www.uea.ac.uk/env/solas/summerschool/programme.html). Practical workshops included a research cruise near Cargèse, laboratory experiments, computer modeling, meteorological

observations and instruction in giving talks and posters. The experience culminated in student presentations on a variety of research topics.

The quality and enthusiasm of the students, selected from an applicant pool of more than 270, was impressive. Probing questions during the presentations and interactions kept the lecturers on their toes. Lecture topics focused on broad overviews of the large-scale processes that control the distribution of the compounds relevant to climate in the surface ocean and lower atmosphere.

Lectures in early morning and late afternoon alternated with practical lessons and student presentations. The practical lessons gave students exposure to ongoing research activities in the program. Groups of 10 participants each went on three-hour research cruises aboard the French research ship N/O Thetys II, which included CTD casts, net tows and species enumeration using on-board microscopes.

Air-sea surface processes and flux measurement systems, provided by and shipped over by Wade McGillis, exposed students to state-of-the-art studies of heat, momentum and gas exchange. Another lesson covered basic modeling tools and their applications. In addition, all students participated in communication sessions where they prepared and practiced concise presentations based on the research they had performed at their home institution.

Students gave oral presentations before the entire school in the second week. Each student used techniques learned at the practical sessions to provide an articulate and concise overview of his or her work. All students also presented posters, which were displayed at sessions held in the school courtyard.

The program's organizers and lecturers, many of whom have spent the last several years organizing SOLAS, found tremendous satisfaction in working with students from around the world with strong interests in the effects of climate and global change on the ocean and atmosphere. The great success of the school owes much to the tireless efforts of the organizer, Corinne LeQuéré of the Max-Planck Institut für Biogeochemie and her committee. Because of the success of this first SOLAS school session in 2003, it was held again in early September 2005: see the SOLAS website or join the email list to keep up to date with this and other aspects of the SOLAS program.

Travel costs for United States students, organizers and lecturers were covered by generous grants from the National Science Foundation, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration and the Office of Naval Research. Details of the summer school can be found on its web site:
(**http://www.uea.ac.uk/env/solas/summerschool**).

**Table 1: Information and comments from the 2003 USA-sponsored SOLAS students, including student background, activities, and review of the program.**

| | SOLAS Student | Research Advisor | Academic Institution | Research Area/Thesis Topic | Current Activity and Comments 2003 SOLAS Summer School |
|---|---|---|---|---|---|
| 1 | John Beman | Pamela Matson | Stanford University | Land-Sea Nitrogen Biogeochemistry: Interactions at the Yaqui Valley-Gulf of California Interface | SOLAS really contributed to my understanding of global ocean biogeochemistry, how it varies in three spatial dimensions and through time. The lecturers did a spectacular job of synthesizing the current state of research, and as a result, I have a tremendous amount of background knowledge that has advanced my ability to think about ideas and hypotheses and interpret results. The practical training provided was also excellent, in particular learning state-of-the-art techniques for measuring gas exchange, and training on preparing and presenting posters and talks. Finally, I met a fantastic cohort of current and future oceanographers/atmospheric scientists from around the world, and those contacts and the exchanges they bring about are invaluable to a young scientist. |
| 2 | Michelle Benoit | Raphael Kudela | Univ California Santa Cruz | | |
| 3 | Jeffery Greenblatt | Jorge Sarmiento | Princeton University | | |
| 4 | Roberta Hamme | Steve Emerson | University of Washington | Geochemistry of inert gases with applications to bubble-mediated gas exchange and productivity: Applications of neon, nitrogen, argon and oxygen to physical, chemical and biological cycles in the ocean | I am currently a Postdoc at Scripps Institution of Oceanography with Ralph Keeling. I am developing methods for the continuous analysis of gases in seawater, continuous analysis of oxygen in the atmosphere, and discrete analysis of noble gases in seawater. The SOLAS summer school brought together a wide variety of people involved in air-sea gas exchange, and was therefore an excellent networking opportunity for young scientists. I formed connections with people in my specialty that I expect to result in future collaborations, and also broadened my understanding of the wider gas exchange field in ways that will help to expand my research interests. The school presented an exceptional learning opportunity, which I would highly recommend to future students. |
| 5 | Michael Hiscock | Richard Barber | Duke University | Regulation of Primary Productivity in the Southern Ocean | I have started a Post-Doc with Jorge Sarmiento at Princeton University. I am working on improving the representation of biological mechanisms within global circulation models.<br><br>In my mind SOLAS summer school had two primary purposes: 1) to introduce scientists of specific environmental expertise to the background and significance of the various other disciplines within environmental science and 2) to introduce those scientists to each other in order to facilitate networking and future cooperation. SOLAS succeeded enormously in achieving these goals. During the two weeks of seminars, lunches, dinners, workshops, and presentations I learned a great deal but I also was able to imagine how I could collaborate with the other students in the future. SOLAS attracted bright, interesting and likely successful scientists from around the World. As a result of SOLAS summer school I have a much deeper understanding and appreciation for many more scientific disciplines and I have had the benefit of greeting a familiar SOLAS face at every conference I've been to since the summer school.<br><br>Wade, thank you very much for making it possible for me to attend. |

| | | | | | |
|---|---|---|---|---|---|
| 6 | Elke Hodson | Ron Prinn | Massachusetts Institute of Technology | Halogen emissions from US/UK/Indian landfills | While my thesis topic is not directly related to SOLAS, I was able to forge contact in an area of research which I am very keen to transition into. I was able to add an extra member to my thesis committee because of contacts made during the summer school. I also continue to be in close contact with the halogen SOLAS community. |
| 7 | Laurie Juranek | Paul Quay | University of Washington | | |
| 8 | Jan Kaiser | Mike Bender | Princeton University | Biological productivity in the tropical Pacific; Isotope ratio measurements of nitrate and nitrous oxide | Compared to two previous summer/winter schools on similar subjects I have attended, this was the best of all, in all matters, organization, location, subjects covered, atmosphere, etc.. The relationship between the participants themselves and between participants and lecturers was very good, direct and uncomplicated. Excellent feedback was received on posters and talks, both regarding contents and presentation. |
| 9 | Veronica Lance | Richard Barber | Duke University | Quantum yield variability in relation to iron availability in HNLC regions; PhD candidate this year. | The 1st SOLAS summer school was overwhelmingly successful in gathering together students and top scientists from many countries and cultures who shared a common interest in the interactions of ocean, atmosphere and climate. The format of lectures, labs and student presentations was highly effective. The SOLAS school was the highlight of my PhD coursework. I would enthusiastically recommend the 2005 school to motivated graduate students and post docs as a way to expand their interdisciplinary knowledge, skills and professional associations. |
| 10 | Nicole Lovenduski | Nicolas Gruber | Univ California Los Angeles | Impact of the Southern Annular Mode on Southern Ocean Circulation and Biogeochemistry | The SOLAS summer school provided me with the opportunity to expand my knowledge of biogeochemistry and air-sea interaction, which I found extremely helpful given that the Ph.D. program at UCLA does not offer many courses in these topics. The school also provided interaction with other important scientists and graduate students in the field, of whom many will become future colleagues. Overall, I would have to rate my experience at the SOLAS summer school as excellent and I would highly recommend it for other Ph.D. students.<br><br>I am currently continuing work on my Ph.D. thesis at UCLA's Department of Atmospheric and Oceanic Sciences. |
| 11 | Christa Marandin | Eric Saltzman | Univ California Irvine | Eddy correlation measurements of DMS and Acetone air-sea flux using APICIMS | The SOLAS summer school was an excellent opportunity to meet colleagues in similar fields, while establishing a network for future job placement. The summer school also provided a nice synopsis of the important areas of research regarding air-sea interactions, which was especially good for formulating future research ideas.<br><br>Currently analyzing equatorial to northern pacific cruise data (summer 2004); specifically, DMS and acetone fluxes and acetone budget. |
| 12 | Bryan Mignone | Jorge Sarmiento | Princeton University | Ocean carbon cycle modeling with a side interest in environmental economics | I spent much of the last year as a Graduate Fellow in the Science, Technology and Environmental Policy Program at the Woodrow Wilson School of Public and International Affairs here at Princeton, where I was looking at the economics of environmental treaty-making. Recently, I've gone back to working on my dissertation project, namely, using GCMs to look at carbon uptake in the Southern Ocean. Will be doing this for the next year or so.<br><br>SOLAS Summer School was a fantastic opportunity (1) to gain exposure to topics and methods outside of one's major field (for me the experimental projects were very interesting), (2) to interact with young members of the biogeochemistry community in an international setting and to make strong personal and professional connections and (3) to see Corsica! I'd highly recommend it to any graduate students in related fields and hope that the program continues to be well funded. |

| | | | | | |
|---|---|---|---|---|---|
| 13 | Payal Parekh | Ed Boyle | Massachusetts Institute of Tech | Decoupling of Iron and Phosphorus in the Global Ocean | I have a couple of post-doc offers in Europe that I am considering. With the other students, I have a new network of peers that I expect to work with. It is nice to attend conferences and always meet a former SOLAS summer school participant! The SOLAS summer school was a great opportunity to integrate knowledge about ocean-atmosphere interactions from biological, chemical and physical perspectives. It also gave me contacts with scientists that I am pursuing job opportunities with. |
| 14 | Joseph Salsibury | Janet Campbell | University of New Hampshire | Satellite indices of fluvial influence in coastal waters | This was an incredible program, bringing together a group of aspiring investigators and accomplished PI's. Everything worked! I am now a Research Scientist at UNH. |
| 15 | Diedre Toole | David Siegel | Univ California Santa Barbara | Light-driven biogeochemical cycling of dimethylsulfide (DMS) in the Sargasso Sea | The SOLAS summer school was a fantastic opportunity to learn about many of the diverse scientific problems that occur at the air-sea interface and learn where my particular area of study fits into the 'broader picture'. It was extremely beneficial to meet my colleagues of the future and some of the more established scientists in an informal setting fostering discussion. I would highly recommend this experience to any PhD student whose work is related to the goals of SOLAS. Any chance you still need help with the 2005 summer school?<br><br>Now at: Postdoctoral fellowship at WHOI; Ocean and Climate Change Institute; Postdoctoral Scholar (w/ Scott Doney) |
| 16 | Andrea van der Woude | Raphael Kudela | Univ California Santa Cruz | | |
| 17 | Roland von Glasow | Paul Crutzen | Max-Planck-Institute for Chemistry, Mainz, Germany<br><br>Postdoc at Scripps during the 2003 SOLAS Summer School | Halogen chemistry in the marine boundary layer, cloud microphysics in MBL. Thesis title: "Modeling the gas and aqueous phase chemistry of the marine boundary layer" | The SOLAS Summer School was great! I really enjoyed the interaction with students and lecturers, the summer school broadened my knowledge significantly and I see more links between chemistry, biology, and physics than before. The summer school also increased my motivation for science. I strongly recommend it for PhD students and young postdocs in this field.<br><br>Now at:<br>Institut fuer Umweltphysik<br>Im Neuenheimer Feld 229<br>Universitaet Heidelberg<br>69120 Heidelberg<br>Germany<br><br>Head of a junior research group (1 postdoc, 2 PhD students, myself) at the University of Heidelberg, Germany: "Atmospheric Chemistry and Climate: Importance of the marine troposphere and halogen chemistry"; research on halogen chemistry, sulfur chemistry, new particle formation in marine atmosphere, chemical exchange between ocean and atmosphere; all work is numerical model with close collaboration with experimentalists. |
| 18 | Suzanne Zvalaren | Joan Willey | University of North Carolina | | |

## SOLAS Future Challenges

The study of surface ocean-lower atmospheric processes requires a thorough knowledge of the state and variability of (1) marine biogeochemistry, (2) air-water gas exchange rates, (3) atmospheric trace gases and particles, and (4) climate. In the past, these fields of research have mostly progressed in parallel and the state of the art in each of these fields is separately reviewed. The challenge of SOLAS and the value of the SOLAS school is to bring scientists from these different backgrounds together to work collaboratively.

Marine biogeochemistry consists of the state of ocean physics, chemistry, and marine biology that determines the oceanic conditions triggering a transfer of gas or particles to and from the atmosphere. Marine biological productivity occurs at the ocean surface, but as organisms die and sink to the deep ocean, trace elements are transported away and become isolated from the atmosphere (this mechanism is known as the "biological pump"). Biological productivity is sustained by the input of nutrients from the atmosphere, rivers and continental margins, and the deep ocean. Whereas nitrate and phosphate are the most common limiting nutrients, recent experiments have demonstrated that iron may also limit biological productivity over large regions of the ocean (Martin et al., 1994; Coale et al., 1996; Boyd et al., 2000). These studies highlight the role of different phytoplankton groups in the efficiency of the biological pump. Efforts are underway to characterize specific properties of the main phytoplankton groups (see for example the iron addition experiments). Biological processes determine the concentration of atmospheric $CO_2$ on time scales of a few thousand years, while contributing to regional patterns of air-sea $CO_2$ fluxes on shorter time scales. Biological processes also affect the sulfur cycle. Process studies have established a general link between phytoplankton and dimethylsulphide (DMS) levels, although the exact mechanisms responsible for DMS production are not fully understood. DMS is a direct feedback on climate through its radiative forcing, and an indirect feedback because it is a source of cloud condensation nuclei, and thus can change cloud properties.

The physics of gas exchange governs the transfer of greenhouse gases at the air-sea interface. Gas exchange rates have either been extrapolated from laboratory measurements or measured in the field. Laboratory measurements have proven useful in elucidating the fundamental physicochemical mechanics of gas exchange. For example, studies in wind tunnels defining the impact of synthetic and natural surfactants on wave slope and gas exchange rates have provided insights into underlying processes. However, some field measurements using the dual tracer technique seem to contradict these findings (for example, Nightingale et al., 2000) and more fieldwork is clearly needed. At higher wind speeds the challenge of making useful measurements of near-surface and interfacial processes increases. Acoustical methods have proven helpful in the study of wave breaking and in delineating bubble distributions. The size distribution depends on the prior life history of the bubbles, from their formation in breaking waves, through turbulent mixing, advection and loss by buoyancy and dissolution. Measurements of bubble sizes in the context of these processes provide a sensitive diagnostic basis for exploring the detailed physics of the upper ocean boundary layer.

In the atmosphere, sea-salt particles are a major reactive medium and precursors for volatile reactive halogens as well as a significant source of atmospheric alkalinity and organic material. The production of several classes of compounds as well as the chemical processing and deposition of important sulphur and nitrogen species are directly tied to sea-salt cycling. Sea salt is also an important source of condensation nuclei and thus can change cloud properties including the radiation effects of clouds. In some regions, reactive halogen compounds (Cl, Br, and I) play major roles in the photochemical processing of air in the marine boundary layer. Currently organo-halogen gases contribute about 25% of the equivalent chlorine to the stratosphere and contribute significantly to the loss of stratospheric $O_3$ (Solomon, 1999). Halogens change greenhouse forcing both directly (through the IR absorption of ozone) and

indirectly via the change in the tropospheric oxidation capacity, which controls the lifetimes and atmospheric abundances of greenhouse gases such as $CH_4$ and H-CFCs. The ocean is also a source of biogenic volatile organic compounds and of myriad heavier organic compounds, many of biological origin, which may affect air-sea gas exchange rates.

The most recent scientific assessment of climate stated that the increase in greenhouse gases and aerosol concentrations likely caused most of the observed warming of the 20th century (IPCC-2001). Changes in the climate system have also been observed in the global water cycle, cloud cover, and the extent and thickness of sea ice, with potential impact on wind patterns and ocean circulation. Better quantification of the physics of climate can account for most of these changes. In particular, in recent years the radiative forcing of greenhouse gases and cloud-albedo feedback were better quantified. As a consequence of human activities the role of air-sea gas and particle exchange must be put in a global context. Ocean-atmospheric coupling has already made measurable impacts on several aspects of the global climate system. By bringing scientists from different backgrounds together, we plan to teach young scientists the current state-of-the-art research techniques in these different fields. We also hope to find innovative ways to understand and quantify the impact of climate change on air-sea processes and to quantify the magnitude of potential feedbacks on climate and weather.